SMC-TR-95-34

AEROSPACE REPORT NO.
TR-95(5940)-1

Spacecraft Anomalies Database Study

15 December 1994

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El Segundo, California

This report was submitted by The Aerospace Corporation, El Segundo, CA 90245-4691, under Contract No. F04701-93-C-0094 with the Space and Missile Systems Center, 2430 E. El Segundo Blvd., Los Angeles Air Force Base, CA 90245. It was reviewed and approved for The Aerospace Corporation by A. B. Christensen, Principal Director, Space and Environment Technology Center. Maj. Leslie O. Belsma (SMC/IMO) was the project officer.

This report has been reviewed by the Public Affairs Office (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

Leslie O. Belsma, Major USAF
SMC/CIB

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	15 December 1994	

4. TITLE AND SUBTITLE
Spacecraft Anomalies Database Study

5. FUNDING NUMBERS
F04701-93-C-0094

6. AUTHOR(S)
H. C. Koons

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
The Aerospace Corporation
Technology Operations
El Segundo, CA 90245-4691

8. PERFORMING ORGANIZATION REPORT NUMBER
TR-95(5940)-1

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Space and Missile Systems Center
Air Force Materiel Command
2430 E. El Segundo Boulevard
Los Angeles Air Force Base, CA 90245

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
SMC-TR-95-34

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

A study was conducted to provide an assessment of the capability of using existing databases to determine the seriousness of environmental effects on spacecraft. The conclusion of this study is that at least 20% of all anomalies, including some satellite failures, have been caused by environmental effects. However, existing databases are inadequate to determine the complete extent of environmental effects on satellites. The most serious problem with existing databases is the lack of anomaly time and spacecraft position information. These are essential to relating anomalies to the space environment.

14. SUBJECT TERMS
Spacecraft, Space environment, Anomalies

15. NUMBER OF PAGES
11

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

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Introduction

A study was conducted to provide an assessment of the capability of using existing databases to determine the seriousness of environmental effects on spacecraft. The conclusion of this study is that at least 20% of all anomalies, including some satellite failures, have been caused by environmental effects. However, existing databases are inadequate to determine the complete extent of environmental effects on satellites. The most serious problem with existing databases is the lack of anomaly time and spacecraft position information. These are essential to relating anomalies to the space environment.

In order to assess the environmental effects on spacecraft it is essential that each and every orbital incident be assigned a record, and that each record be tagged with the time of the incident (as close as feasible given telemetry coverage) and with the location of the satellite.

This report documents the results of the Spacecraft Anomalies Database Study. The purpose of this study was to provide an assessment of the capability of using existing databases to determine if environmental effects on spacecraft are significant.

This study was performed eight years ago. The databases used for the study are no longer maintained. Separate databases are currently maintained by NOAA, the Air Force 50th Weather Squadron at Falcon AFB, and individual Program Offices. The latter generally do not conform to the standards of those maintained by NOAA and the AF 50th WS.

Orbital Data Acquisition Program (ODAP) Database

The major database used for this study was the database from the Orbital Data Acquisition Program (ODAP). ODAP is a depository of on-orbit incidents that provides a capability to print subsets of failure reports keyed to hardware/software type failures, satellite program, manufacturer, environments, quality of workmanship, orbital phase, seriousness of anomaly, etc. This data system provides a unique history of incidents with interpretation of anomalies and failures and the assemblies, subassemblies, or modules in which each occurred for the U.S. Air Force and selected other satellites listed in Table 1. In addition approximately 90 non-Air Force satellites are included in the database. This database was provided to us by the Reliability Department at The Aerospace Corporation. An example of a record from this database showing the mission failure of DSCS 2 is shown in Figure 1.

System Operability Update, Review and Characteristics Evaluation (SOURCE) Program Printouts were also obtained.[1] This document incorporates on-orbit anomaly information through FY82 for a Space Division Operational Program. The database was analyzed by Kelley Spearman. A summary was presented at the Spacecraft Anomaly Workshop.[2]

A variety of lists of anomalies for specific Air Force satellites has been collected. Generally, they are in the form of type-written tables with added hand annotations. Most of them are already contained in the ODAP.

The quality of all available databases for a statistical study of environmental anomalies ranges from fair to poor. The largest database, ODAP, is oriented toward hardware failures. It appears to be an excellent database for that purpose. However, it does not contain the information needed for an assessment of the role played by the environment. The time and date of each occurrence is not contained in the database. There are redundant entries, and many occurrences of the same symptom are lumped into one record as shown In Figure 2. When a recurring problem is identified, it is often referenced, and then future occurrences are omitted.

Table 1. Air Force satellites in the ODAP database.

CL - Classified Programs	NATO 2 and NATO 3
DMSP	SKYNET 1 and SKYNET 2
DSCS 2 and DSCS 3	SPACE TEST PROGRAM
FLTSATCOM	TAC COMSAT
GPS	VELA
IDCSP	

```
INCIDENT      19          PROGRAM -DSCS 2          FLIGHT NO. -01                LAUNCH DATE-71 NOV
  SUBSYSTEM              -TELEMETRY TRACKING AND COMMAND
  ASSEMBLY               -PCM ENCODER
  SUBASSEMBLY OR TYPE-MULTIPLEXER
  MODULE OR TYPE         -NON MICROPROCESSOR
  CAUSE             -DESIGN,MAGNETIC STORM,ELECTROSTATIC DISCHARGE
  FAILURE TIME - 15        MANUFACT-GEN DYNAMC       DUTY CYCLE -100          CLASS        -ELECTRICAL
  REPORT NO.     :1-19       FEEDBACK-ANOMALIES       CRITICALITY-GLITCH       ORITAL PHASE-STEADY ST
                 ***    SYMPTOM - SEVERAL LOSSES OF TELEMETRY SYNCH OCCURRED AT GROUND STATION    ***
                 ***    CAUSE - TRANSIENT ON ENCODER TO MULTIPLEXER SYNCH LINE, POSSIBLY DUE      ***
                 ***      TO MAGNETIC SUBSTORM                                                    ***
                 ***    RECOVERY METHOD - NONE                                                    ***
                 ***    CORRECTIVE ACTION - GROUNDED ALL(WHERE POSSIBLE)EXTERNAL CONDUCTIVE       ***
                 ***      SURFACES TO ELIMINATE DIFFERENTIAL CHARGING DURING SUBSTORM             ***
                 ***    COMMENT-SIMILAR PROBLEM FLIGHTS 2,4,13 (SEE F.R.2-10,4-6,13-14)           ***

INCIDENT      21          PROGRAM -DSCS 2          FLIGHT NO. -01                LAUNCH DATE-71 NOV
  SUBSYSTEM              -ELECTRICAL POWER AND DISTRIBUTION SUBSYSTEM
  ASSEMBLY               -LOAD CONTROL
  SUBASSEMBLY OR TYPE-POWER INTERFACE SWITCHING
  MODULE OR TYPE         -
  CAUSE             -DESIGN,MAGNETIC STORM,ELECTROSTATIC DISCHARGE
  FAILURE TIME - 19        MANUFACT-TRW              DUTY CYCLE -100          CLASS        -ELECTRICAL
  REPORT NO.     :1-21       FEEDBACK-GAP             CRITICALITY-MISSION      ORITAL PHASE-STEADY ST
                 ***    SYMPTOM - NO POWER TO COMMUNICATION SUBSYSTEM, MISSION TERMINATED         ***
                 ***    CAUSE - SWITCHING LOGIC ASSEMBLY COMMANDS INEFFECTIVE, DESPUN POWER       ***
                 ***      LOSS DURING GEOMAGNETIC STORM                                           ***
                 ***    RECOVERY METHOD - NONE                                                    ***
                 ***    CORRECTIVEACTION - GROUNDED ALL(WHERE POSSIBLE) EXTERNAL CONDUCTIVE       ***
                 ***      SURFACES TO ELIMINATE DIFFERENTIAL CHARGING DURING SUN STORM            ***
```

Figure 1. Sample from database showing mission failure of DSCS 2.

The smaller tables of anomalies are virtually useless. They contain program-specific acronyms that would have to be interpreted by someone who is reasonably familiar with the details of the spacecraft. Also, some of these data were already contained in the ODAP.

We have made two attempts to use the ODAP database to determine the significance of environmental effects on spacecraft. The results are described in the next two sections.

```
INCIDENT      72          PROGRAM -DSCS 2          FLIGHT NO. -04               LAUNCH DATE-73 DEC
  SUBSYSTEM              -COMMUNICATIONS PAYLOAD SUBSYSTEM
  ASSEMBLY               -RECEIVER
  SUBASSEMBLY OR TYPE-IF AMPLIFIER(NON LINEAR)
  MODULE OR TYPE         -TUNNEL DIODE AMPLIFIER LIMITER
  CAUSE               -DESIGN,MAGNETIC STORM,ELECTROSTATIC DISCHARGE
  FAILURE TIME -  0         MANUFACT-AERTECH         DUTY CYCLE -100          CLASS        -ELECTRICAL
  REPORT NO.     :4-5       FEEDBACK-ANOMALIES       CRITICALITY-GLITCH       ORITAL PHASE-INFANT MOR
               ***  SYMPTOM - GAIN CHANGES IN TUNNEL DIODE AMPLIFIER LIMITER WHICH IS A     ***
               ***    TYPE OF IF AMPLIFIER IN THE RECEIVER                                   ***
               ***  CAUSE - MAGNETIC SUBSTORM                                                ***
               ***  RECOVERY METHOD - RESET GAIN BY GROUND COMMAND                           ***
               ***  CORRECTIVE ACTION - SATELLITE SHIELDING AND GROUNDING IMPROVED,          ***
               ***    ISOLATION ADDED TO GAIN CONTROL LOGIC, ADDED RESISTORS TO REDUCE       ***
               ***    TUNNEL DIODE AMPLIFIER LIMITER GAIN CONTROL NOISE SENSITIVITY          ***
               ***    FLIGHT 7 ON                                                            ***
               ***  COMMENT-REPEAT OCCURRENCES,OCCURRED ON 22,25,29 DEC 19.3, 3,11,26,30     ***
               ***    JAN,20,27 JUL,18,24 AUG,23 SEP,2,7,11,12,14,23,24 OCT,16,18,20,24,25   ***
               ***    NOV,14 DEC 1974, 6 JAN,4,10,12 OCT,6,9,16,27 NOV,12 DEC 1975, 5,15,    ***
               ***    23,25 JAN,2,10,15 FEB,3,7,14 MAR,28 SEP,9,17 OCT,5 DEC 1976, 20 JAN,   ***
               ***    8 FEB,22,25 SEP,20 OCT,1,16,19 NOV,16 DEC 1977, 6 JAN,2,23 OCT,14      ***
               ***    NOV,2 DEC 1978, 5 JAN,2,18 OCT 1979, 7 JAN,1 MAR,6,24 OCT,30 NOV,6     ***
               ***    DEC 1980,4 FEB,6 OCT 1981,1,16 JAN,5 MAR,19 SEP,17 NOV,31 DEC(2)       ***
               ***    1982,22,28 JAN,1 MAR,17,23 SEP,19,27 OCT,8,29 NOV,20,28 DEC 83         ***
               ***    13 JAN,7 FEB,11,15,26 SEP,15 DEC 84                                    ***


INCIDENT    1355          PROGRAM -DSCS 2          FLIGHT NO. -04               LAUNCH DATE-73 DEC
  SUBSYSTEM              -TELEMETRY TRACKING AND COMMAND
  ASSEMBLY               -STEERABLE ANTENNA
  SUBASSEMBLY OR TYPE-BIAXIAL DRIVE
  MODULE OR TYPE         -RESOLVER
  CAUSE               -DESIGN,MAGNETIC STORM,ELECTROSTATIC DISCHARGE
  FAILURE TIME -  0         MANUFACT-TRW             DUTY CYCLE -      100     CLASS        -ELECTRICAL
  REPORT NO.    :          4-4FEEDBACK-ANOMALIES     CRITICALITY-GLITCH       ORITAL PHASE-INFANT MOR
               ***  SYMPTOM-RESOLVER ELECTRONIC SELECT LOGIC CHANGES                         ***
               ***  CAUSE-INADVERTENT SWITCHING LOGIC ASSEMBLY (SLA) COMMANDS TRIGGERED      ***
               ***    BY MAGNETIC STORM                                                      ***
               ***  RECOVERY METHOD-S/C WAS RECONFIGURED FROM GROUND STATION                 ***
               ***  CORRECTIVE ACTION-REDESIGNED TO IMPROVE GROUNDING,SHIELDING,ADDED        ***
               ***    RELAYS TO GAIN CONTROL,SLA BUS FILTERED,EXECUTE LINES FILTERED,        ***
               ***    FLIGHT 7 ON                                                            ***
               ***  COMMENT-REPEAT OCCURRENCES,OCCURRED ON 22,29 DEC 1973,3,11,26,30 JAN,    ***
               ***    25 APR,27 JUN,20,27 JUL,18,24 AUG,2,7,12,14,23,24 OCT,16,20 NOV,14     ***
               ***    DEC 1974, 6 JAN,4,12 OCT,6,16,27 NOV,12 DEC 1975, 23 JAN,3,10,15 FEB   ***
               ***    ,3 MAR,5 DEC 1976, 20 OCT,16,19 NOV 1977, 2,23 OCT,2 DEC 1978, 5 JAN   ***
               ***    ,2 OCT 79,24 OCT 80,17 NOV,31 DEC 82,22 JAN,29 NOV 83,15 DEC 84        ***
```

Figure 2. Sample from database showing an environmental anomaly.

Environmental Category

Each of the spacecraft anomalies in the ODAP database have been identified with two levels of causes, a general cause and a specific cause. The general causes used in the database are listed in Table 2. The environment is one of the general causes. Note that the assessment that the environment was a cause was made by somebody before the entry was made in the database. The specific environmental causes are listed in Table 3. Five of these are pertinent to this study: (1) Electrostatic Discharge, (2) Van Allen Belt, (3) Solar Flare, (4) Magnetic Storm, and (5) Deep Space Ion. The last one would now be called a Single-Event Upset (SEU). These causes overlap to a great extent. Electrostatic discharges are frequently caused by satellite surface charging by electrons that have been energized by a magnetic storm. The magnetic storm results from a build up of electrons in the tail of the magnetosphere following a solar flare. The database frequently lists more than one cause for an anomaly.

The database also contains a criticality field. This relates to the severity of an orbital incident. The criticality categories are listed in Table 4.

The database currently contains about 3600 records. Printouts were obtained from the Reliability Department containing the records in each of the five environmental categories listed above. The printouts were hand-searched for the criticality for each incident. The results are summarized in Table 5. There are 431 total incidents (records) that are identified with these five environmental categories. Adding the separate sums from the five categories in Table 5 gives a total of 594. This shows that many of the incidents are identified with more than one environmental category in the database. Even more serious is the use of one record to identify multiple occurrences of the same anomaly. No attempt has been made to quantify this, but it is estimated that the record count is 2 to 3 times less than the anomaly count when multiple references to incidents in one record are considered. Most of the environmental anomalies are classified as glitches. A glitch is defined as an incident that lasts up to two days. A transitory anomaly is one that lasts 3 to 30 days.

Table 5 gives a reasonable overview of the problem. A few major failures have been attributed to environmentally induced anomalies. However, the majority of the problems attributed to the environment have been classified as glitches.

Table 2. General cause of anomalies.

Design	Replaced (obsolete)
Environment	Standby (dormant)
Operation	Unknown
Parts	Wearout
Quality/Workmanship	

Table 3. Environmental causes of anomalies.

Acceleration	Magnetic Storm*
Acoustic Noise	Magnetization
Air Pressure	Micrometeor
Asteroid	RF Interference
Atmospheric Noise	Shock
Bright Objects	Solar Flare*
Contamination	Static Electricity
Deep Space Ion*	Temperature
Eclipse	Ultraviolet Radiation
Electromagnetic Interference	Vacuum
Electrostatic Discharge*	Van Allen Belt*
Gravity	VHF Interference
Humidity	Vibration
Lightning	Water

*Causes considered in this study.

Table 4. Criticality of an orbital incident.

Prime Mission Failure	Temporary Failure
Secondary Mission Failure	Degraded Performance
Redundant Unit Failure	Temporary
Work around Failure	Transitory
Serendipity Failure	Glitch
Single Point Failure	Intermittent
Failure	

Table 5. Spacecraft anomalies by Environmental Category

	Glitch	Degrade Perform	Single Part Failure	Transitory	Redundant Unit	Work Around	Temporary	Mission	Total
ESD	114	7	1	2	5	2	2	2	135
DEEP SPACE ION	184	9	0	0	2	4	1	2	202
VAN ALLEN BELT	21	8	0	0	0	8	1	7	45
SOLAR FLARE	37	35	4	3	1	1	1	4	86
MAGNETIC STORM	111	7	0	0	4	1	2	1	126
TOTAL	467	66	5	5	12	16	7	16	594

Reclassification

The classification scheme in the ODAP was not specific enough to allow the assessment of the significance of the environmental effects on spacecraft. The anomalies have been reclassified into six categories: (1) Mission Failure, (2) Random Part Failure, (3) Degraded Performance, (4) Phantom Commands, (5) Spurious Signals, and (6) Command Errors.

All redundancies have been removed from anomalies attributed to Electrostatic Discharges in the ODAP printout, and the specific incidents have been listed by category and program in Table 6. This gives a much better picture of the seriousness of the problem.

Table 6. Anomalies cause by electrostatic discharges.

I. Mission Failure	
1.	Power lost to communication subsystem (DSCS 2).
2.	(GOES 2).
II. Random Part Failure	
1.	Thermistor (CL 1).
2.	Reset Generator lockup in reset state (DSCS 2).
3.	Analyzer wheel locked against a mechanical stop (VOYAGER)
4.	Clocks (GPS).
III. Degraded Performance	
1.	Link signal strength decreased 5 dB and data was noisy (CL 1).
2.	Plasma Monitor calibration change (DMSP).
3.	Telemetry sync losses (DSCS 2).
4.	Shift in clock frequency (GPS).
5	Sudden drop of 15 percent in solar array power (HERMES).
6.	Eight telemetry words lost permanently (INTELSAT 5).
7.	Solar array shunt current telemetry lost (INTELSAT 5).
8.	Malfunction in command system resulted in 2-month delay in operations (MARECS).
IV. Phantom Commands	
1.	Focal plane heater switched from enable to inhibit.
2.	Star sensor threshold level changed from 1 to 2 (CL 1).
3.	Amplifier gain changes (DSCS 2).
4.	Beacon gain settings (DSCS 2).
5	Azimuth motor step changes (DSCS 2).
6.	Resolver electronic select logic changes (DSCS 2).
7.	Loss of earth lock and spin-up (DSCS 2).
8.	Extraneous switching of low-level logic signals in Switching Logic Assembly (DSCS 2).
9.	Command message length flip-flop reset (DSCS 2).
10.	Radiometer sounder configuration change disrupted operation 22 times (GOES).
11.	Radiometer PM tube gain changed (GOES).
12.	Interruption of video imagery (GOES).
13.	Solar array drive motors reconfigured to hold mode from auto- track mode (GPS).
14.	Bypass timer shutoff (GPS).
15.	S/C was acquired in an anomalous data rate (GPS).

16. Antenna electronics anomalously switched to a redundant unit (INTELSAT 3).
17. Despun platform spun up (INTELSAT 3).
18. PCM encoder switched modes causing loss of data (INTELSAT 4).
19. Loss of despin control caused despin platform to drive off the earth (INTELSAT 4).
20. Erroneous command appeared in decoder command register (INTELSAT 4).
21. Loss of earth lock due to switch of "sensor in control" and change from "torque" to "speed" mode (INTELSAT 5).
22. Reconfigurations of attitude determination and control systems such as scan inhibition of earth sensors (INTELSAT 5).
23. Momentum wheel's automatic unload function disabled (INTELSAT5).
24. L-band transponder tripped (INTELSAT 5).
25. Pitch control was transferred to speed mode resulting in loss of earth lock (INTELSAT 5).
26. Spurious telemetry switchings (MARECS)
27. Antenna pointing errors (NATO 3)
28. Heaters turned on. Reduced communications power by 2 dB. (PIONEER)
29. Magnetometer filter changes gain. (P78-2)
30. Processor clock jumped by 16 seconds (P73-5)
31. Despin electronics control switched automatically (TAC COMSAT).
32. Uncommanded switchoffs in military and civilian repeater packages. (TELECOM).
33. Eight second timing error in computer command subsystem. (VOYAGER)
34. Imaging camera reset a number of times (VOYAGER).

V. Spurious Signal

1. From toggling switch between preamp power converter units of IR sensor (CL 1).
2. Impact sensor indicated a false alarm (CL 1).
3. Noise strobes over the focal plane (CL 1).
4. Preprocessor Strobe Alarms (CL 1).
5. Temperature sensor made a step increase of 43 deg (CL 1).
6. Gain changes in tunnel diode amplifier (DSCS 2).
7. Telemetry flip-flop monitor for commanding despin incorrect (DSCS 2).
8. Erroneous signals from multiplexer (DSCS 2).
9. Vehicle command count errors (register shift) (GPS).
10. Anomalous PCM encoder register reconfiguration (GPS).
11. Telemetry calibrations shifted upwards (INTELSAT 5).

VI. Command Errors

1. Incorrect response to sensitivity level command In star sensor (CL 1).
2. Command scramble resulted in despin controller losing earth lock (DSCS 2).
3. Satellite spinning up (DSCS 2).

There have been two mission failures attributed to the environment, DSCS 2 and GOES 2. The most serious "Random Part Failure" was the loss of the clocks on the GPS satellites.

The largest category is Phantom Commands. These are uncommanded reconfigurations of the vehicle. Since the area of susceptibility is not discovered until the vehicle is in orbit, this may prove to be the most serious problem. A disconcerting number of them seems to occur in the attitude control subsystem. Frequently, these phantom commands occur when the vehicle is not being monitored.

The term "glitch" used in the ODAP to identify the criticality of most of the incidents listed in Table 6 would seem to understate the seriousness of the problems that have been associated with the environment.

References

1. System Operability Update, Review and Characteristics Evaluation (SOURCE) program Printouts, Aerospace Report No. TOR-O083(3409-34)-1, The Aerospace Corporation, 15 October 1982.

2. K. R. Spearman, "A Case Study at Geostationary Altitude," presented at the Spacecraft Anomaly Workshop, Boulder, Colorado, 2-4 October 1985.

TECHNOLOGY OPERATIONS

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